Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

AD-A216 668

DTIC ELECTE JAN 09 1990 S B D

REPORT DOCUMENTATION PAGE

- 1a. REPORT SECURITY CLASSIFICATION: unclassified
- 1b. RESTRICTIVE MARKINGS:
- 2a. SECURITY CLASSIFICATION AUTHORITY:
- 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:
- 3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release. Distribution unlimited.
- 4. PERFORMING ORGANIZATION REPORT NUMBER(S): Technical Report Number 16
- 5. MONITORING ORGANIZATION REPORT NUMBER(S): Office of Naval Research
- 6a. NAME OF PERFORMING ORGANIZATION: University of Massachusetts
- 6b. OFFICE SYMBOL (If applicable):
- 7a. NAME OF MONITORING ORGANIZATION: Office of Naval Research
- 6c. ADDRESS (City, State, and ZIP Code): Dept. of Chemistry, Univ. of Massachusetts, Amherst, MA 01003
- 7b. ADDRESS (City, State, and ZIP Code): 800 N. Quincy Street, Arlington, VA 22217
- 8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Office of Naval Research
- 8b. OFFICE SYMBOL (If applicable):
- 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-86-K-0345
- 8c. ADDRESS (City, State, and ZIP Code): 800 N. Quincy St., Arlington, VA 22217
- 10. SOURCE OF FUNDING NUMBERS:

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

- 11. TITLE (Include Security Classification): Metal Coordination Polymers as Potential High-Energy Lithographic Resists (unclassified)
- 12. PERSONAL AUTHOR(S): Ronald D. Archer, Valentino J. Tramontano, Ven O. Ochaya, Paul V. West & William Cumming
- 13a. TYPE OF REPORT: Preprint
- 13b. TIME COVERED: FROM ____ TO ____
- 14. DATE OF REPORT (Year, Month, Day): 89 05 15
- 15. PAGE COUNT: 10
- 16. SUPPLEMENTARY NOTATION: To appear in Volume 61 of Polymeric Materials Science and Engineering, Sept. 1989
- 17. COSATI CODES:

FIELD	GROUP	SUB-GROUP

- 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): metal coordination polymers, lithographic resists, cobalt polymers, chromium polymers, positive resists, beta-diketones
- 19. ABSTRACT (Continue on reverse if necessary and identify by block number):

Over the past few years we have developed a number of linear coordination polymers which have interesting properties. One type of study has centered on polymers which would provide sensitive lithographic resists based on the fact that the photoelectric effect interacts with nuclei approximately to the fourth power of the atomic number. We have prepared a number of uranyl carboxylate polymers which are very sensitive to gamma and electron beam radiation with G_s values higher than any currently available resist material [Archer, Hardiman, & Lee, 1987]. We have extended this work to cobalt and chromium coordination polymers as well. Coordination polymers of other metals are also under development.

90 01 ... 0 0

- 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS
- 21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
- 22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. Kenneth Wynne
- 22b. TELEPHONE (Include Area Code): (202) 9696-4409
- 22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE: Unclassified

OFFICE OF NAVAL RESEARCH

Contract No. N00014-86-K-0345

R & T Code 413c028

TECHNICAL REPORT NO. 16

METAL COORDINATION POLYMERS AS POTENTIAL HIGH-ENERGY LITHOGRAPHIC RESISTS

by

R. D. Archer, V. J. Tramontano, V. O. Ochaya, P. V. West and W. Cumming

Department of Chemistry, University of Massachusetts
Amherst, Massachusetts 01003

Accepted for Publication
in

Polymeric Materials Science and Engineering
Volume 61, September 1989

May 15, 1989

METAL COORDINATION POLYMERS AS POTENTIAL HIGH-ENERGY LITHOGRAPHIC RESISTS

R. D. Archer, V. J. Tramontano, V. O. Ochaya, P. V. West, and W. Cumming

Department of Chemistry, University of Massachusetts
Amherst, MA 01003

INTRODUCTION

High energy radiation can modify polymers by causing cross-linking and/or degradation. One particularly interesting application is the use of polymers as photo- or electron-resists in lithography (1). Higher density integrated circuit chips have allowed metal oxide semiconductor random access memory device capacity to increase by several orders of magnitude in the recent past with minimum feature size of less than one micron at present. Further reductions are in progress, but diffraction effects will eventually limit the resolution of visible and ultraviolet sensitive resists. However, higher energy electron beams, X-ray, gamma ray, and ion-beam systems can provide the necessary resolution required for submicron resolution. But organic polymers have limited sensitivity to higher energy radiation with G values (chemical events/100 eV absorbed) typically not much greater than one, though sulfur containing organic polymers with G values of about 10 are known. We are using a combination of high G value polymers together with heavy metal atoms (which provide an increased absorption of energy through the photoelectric effect's approximately Z^4 power dependence, where Z = atomic number (2), Figure 1) in order to develop polymers which are very sensitive to high energy radiation (3,4). Whereas the advantage of heavy metal atoms is quite apparent from the uranyl species which we have studied--G_s values of 50 and up even at 662 keV, in the usual 10 - 20 keV range of electron beam studies, 3d-transition-metal polymers should have a tremendous advantage over simple organic polymers. Therefore, in order to get the advantage of the heavier atoms together with the sensitivity of the organic polymers containing sulfide and sulfone bridges, we have synthesized several cobalt(III) coordination polymers, one of which was briefly described earlier (5,6). The general synthesis for three polymers derived from leucinatobis(2,4-pentanedionato)cobalt(III), Co(leu)(acac)$_2$, is shown in equations 1 to 3.

$$Co(NO_2)_6^{3-} + 2\ acac^- \longrightarrow trans\text{-}[Co(acac)_2(NO_2)_2]^- + 4\ NO_2^- \quad (1)$$

where acac$^-$ is the anion of 2,4-pentanedione,

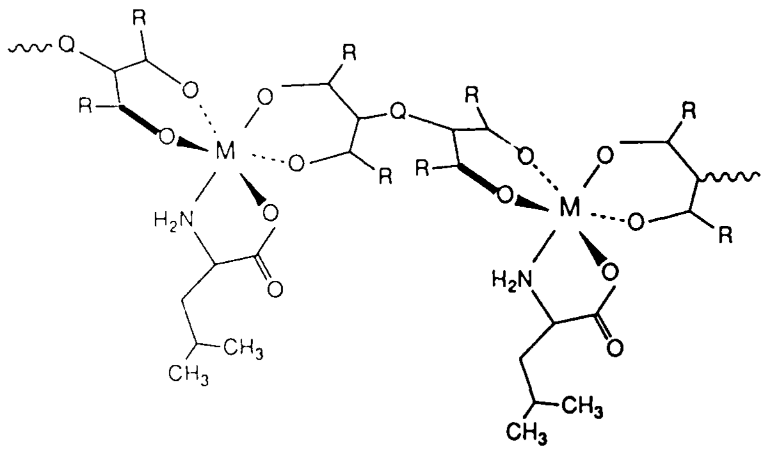
$$[Co(acac)_2(NO_2)_2]^- + leu^- \xrightarrow[\text{Norit A}]{} Co(leu)(acac)_2 + 2\ NO_2^- \quad (2)$$

where leu$^-$ is the anion of leucine,

$$Co(leu)(acac)_2 + QCl_2 \longrightarrow [\text{-acacCo(leu)acac-Q-}]_n + 2\ HCl \quad (3)$$

where Q = S, S_2, or SO, and bridges the beta-diketones from adjacent units in the polymer chains. The corresponding sulfone polymer can be synthesized from the oxidation of the sulfoxide polymer with hydrogen peroxide.

$$[\text{-acacCo(leu)acac-SO-}]_n \xrightarrow[H_2O_2]{} [\text{-acacCo(leu)acac-}SO_2\text{-}]_n \quad (4)$$



Part of typical polymer chain, Q = S, SS, SO, SO_2, M = Co, R = CH_3

As noted below, the cobalt(III) coordination polymers have excellent G_s values, where G_s is the G value for scission. On the other hand, they appear to undergo cleavage only at the C-S and S-S bonds when irradiated at high energy, rather than at the cobalt centers [which would be expected in the ultraviolet region, where cobalt(III) to cobalt(II) charge transfer chemistry occurs for cobalt(III) beta-diketone complexes (7)]. In fact, other than the sulfoxo species, they all appear to have G_s values at least as high as any organic polymers. Coupled with the higher amount of energy absorbed for identical films and their good adhesion to silica-coated silicon, these species have excellent resist potential. In response to the concern of resist special-ists about residual metal ions, it is gratifying to note that no detectable free cobalt ions can be observed after several megarads of irradiation at high energies, either for the monomer or the polymer. This observation led us to consider the more volatile fluorinated chromium(III) beta-diketonates. Progress with the chromium species is also noted herein, though this work has not proceeded as far as the cobalt(III) studies.

EXPERIMENTAL

Solvents and ligands were carefully dried prior to use. Sulfur dichloride and sulfur monochloride were purified just prior to use by appropriate literature methods (8,9).

(S-Leucinato-*N,O*)bis(2,4-pentanedionato-*O,O'*)cobalt(III).--This neutral complex was prepared by the method of Laurie (10). Yields of 20 - 29% of pure Co(leu)$(acac)_2$ were obtained from the reaction between Na[*trans*-$(acac)_2(NO_2)$)] and Na[S-(leu)] after column chromatography, rotary evaporation and recrystallization.
Anal. Calcd for $C_{16}H_{26}NO_6Co$: C, 49.6; H, 6.8; N, 3.6. Found: C, 49.5; H, 6.7; N, 3.6.

(S-Leucinato-*N,O*)bis[2,2,6,6-tetramethyl-3,5-heptanedionato-*O,O'*)cobalt(III).--An analogous reaction between the corresponding 2,2,6,6-tetramethylheptanedionate (or dipivaloylmethanate, dpm), but at much lower concentrations due to limited solubility in water, provided a 15% yield of the intermediate product and a 25% yield of the final Co(leu)$(dpm)_2$ product. FT-NMR carbon-13 results are in agreement with the formulation given.
Anal. Calcd for $C_{28}H_{50}NO_6Co$: C, 60.5; H, 9.1; N, 2.5. Found: C, 60.3; H, 9.0; N, 2.5.

Poly((S-leucinato-*N,O*)-u-[3,3'-dithiobis(2,4-pentanedionato-*O,O'*)]cobalt(III)).--The dropwise addition of 1.7460 g disulfur dichloride (12.93 mmol) in 6 mL dry dichloroethane to 5.0088 g Co(leu)$(acac)_2$ in 20 mL dimethylacetamide (DMAC) with 0.7095 g sodium carbonate (6.69 mmol) as a slurry in the dimethylacetam-ide solution under argon and with vigorous stirring. The mix-ture was stirred for 24 - 36 hr and then precipitated with diethyl ether. Alternatively, the solvent was

removed *in vacuo* at 45°C. The product was collected on a fritted funnel, washed with water, and dried *in vacuo* at 100°C; yield, 5.5 g; 95%. The polymer was fractionated (three times) by a DMAC/acetone or di-methyl sulfoxide/acetone solvent/nonsolvent precipitation to re-move low molecular-weight material.

Anal. Calcd for $[C_{16}H_{24}NO_6S_2Co]_n$: C, 42.8; H, 5.4; N, 3.1; S, 14.3. Found: C, 42.5; H, 5.1; N, 2.9; S, 14.2.

Poly{(S-leucinato-*N,O*)]-u-[3,3'-thiobis(2,4-pentanediona-to-*O,O'*)]cobalt(III)}.--The dropwise addition of 0.7592 g sulfur dichloride (7.37 mmol) in 6 mL dry dichloroethane to 2.8514 g $Co(acac)_2(leu)$ (7.36 mmol) in 60 mL dichloroethane or di-chloro-methane under argon with vigorous stirring. After 24 hr of stirring HCl and the solvent were removed *in vacuo*, washed with water, and dried *in vacuo* at 100°C; yield, 2.76 g; 90%. The polymer was fractionated by an acetone/water fractional precipitation.

Anal. Calcd. for $[C_{16}H_{24}NO_6SCo]_n$: C, 46.0; H, 5.8; N, 3.4; S, 7.7. Found (from $C_2H_4Cl_2$): C, 45.4; H, 5.7; N, 3.0; S, 7.3. Found (from CH_2Cl_2): C, 45.9; H, 5.6; N, 2.8; S, 7.5.

(The use of more polar solvents such as acetonitrile with an acid acceptor proved less satisfactory with SCl_2 than with S_2Cl_2 above.)

Poly(S-leucinato-*N,O*)-u-[3,3'-sulfoxobis(2,4-pentanediona-to-*O,O'*)]cobalt(III)}.--The dropwise addition of 0.9213 g thionyl chloride (7.74 mmol) in 4 mL dry dichloroethane to 2.9925 g $Co(acac)_2(leu)$ in 10 mL dimethylformamide and 15 mL dichloro-ethane under argon with vigorous stirring at 0°C. The mixture was then allowed to stir for at least 24 hr. The solvent and any residual HCl was removed at 45°C *in vacuo*, and the product was dried at 100°C; yield, 3.13 g; 93%. The polymer was fractionated with an acetone/water fractional precipitation.

Anal. Calcd for $[C_{16}H_{24}NO_7SCo]_n$: C, 44.3; H, 5.6; N, 3.2; S, 7.4. Found: C, 44.1; H, 5.3; N, 3.8; S, 6.9.

Poly(S-leucinato-*N,O*)-u-[3,3'-sulfonebis(2,4-pentanediona-to-*O,O'*)]cobalt(III)}.--The dropwise addition of 0.10 mL hydrogen peroxide to 0.0603 g fractionated sulfoxide polymer in 10 mL acetonitrile with vigorous stirring. The mixture was heated to 40°C and stirred for 24 hr. The solvent was removed *in vacuo* at 40°C, and the sample was then dried *in vacuo* at 100°C

Anal. Calcd for $[C_{16}H_{24}NO_8SCo]_n$: C, 42.8; H, 5.4; N, 3.1; S, 7.1. Found: C, 41.0; H, 5.6; N, 3.4; S, 6.9.

Poly{(111-trifluoro-2,4-pentanedionato-*O,O'*)chromium(III)-u-[3,3'-thiobis(2,4-pentanedionato-*O,O'*)}, $Cr(tfa)(acac_2S)$.--The synthesis of this polymer has been based on the reaction of $Cr(tfa)(acac)_2$, which was prepared by the method of Palmer, Fay and Piper (11) with SCl_2 (exact 1:1 mole ratio) in methylene chloride at -10°C. The infrared spectra and the intrinsic viscosity of 0.17 dL/g for the product are consistent with polymerization though the GPC results were less conclusive.

Physical Characterizations.--Gel permeation chromatography, viscosity, scribe-stripping, nuclear magnetic resonance, infrared, and ultraviolet-visible measurements were performed as reported earlier (12). Electron spin resonance spectroscopy measurements were made with an IBM ESP 300 instrument with quartz tubes sealed *in vacuo* prior to irradiation. To remove color centers from the quartz, one end of the tube was heated with a torch while the other was immersed in liquid nitrogen. The sample was then reversed and the process repeated.

Polymer Irradiation.--Samples of the polymers sealed *in vacuo* were exposed to cesium-137 gamma irradiation (662 KeV) at doses ranging from 0.02 to 0.07 Mrad/hr.

RESULTS AND DISCUSSION

Linear coordination polymers of cobalt(III) have been prepared from the reactions of $Co(leu)(acac)_2$ with SCl_2, S_2Cl_2, and $SOCl_2$. The solvents chosen for the different reactions have been determined from a knowledge of the reactivity of the sulfur halides, from the need for solubility throughout the polymerization reaction, and by trial and error. The sulfone polymer was prepared by hydrogen peroxide oxidation of the sulfoxide polymer. Several properties of the polymers are provided in Table 1.

Table 1. Linear cobalt(III) polymers derived from $Co(leu)(acac)_2$

Bridge[a]	M_n(GPC)[b]	M_n(NMR)[c]	Visc[d]	UV/Vis[e]	TGA[f]	Infrared[g]
-S-S-	34,000	$\geq$13,000	0.11	280/553	180°	h,i
-S-	13,500	$\geq$15,000	0.10	279/546	160°	h,i
-SO-	16,000	-	-	276/553	-	1025[h,i]
$-SO_2-$	17,000	$\geq$10,000	0.084	279/548	190°	1160[h,i]

[a]replaces gamma hydrogens of acac's; [b]NMP solvent; polystyrene standards; [c]based on FT-NMR of weak gamma proton signal in DMSO-d_6; [d]intrinsic viscosity, dL/g in NMP at 30°C; [e]nm, molar extinction coefficients about 10^4 and 10^2 $M^{-1}cm^{-1}$ per repeating unit; [f]temperature of first major weight loss; [g]cm^{-1}; [h]780 cm^{-1} monomer gamma C-H mode not observed; [i]1550 cm^{-1} peak replaces two peaks observed at 1570 and 1520 cm^{-1} in monomer.

The number-average molecular weights may be higher than the NMR values because the gamma proton signals (one proton per chain is expected) are still at the noise level after several thousand transients. However, the viscosity of the dithio polymer is more like that expected for the NMR molecular weight value than for the GPC one.

The irradiation of these cobalt polymers with 662 keV gamma rays provides approximate G_s values of 18, 10, 0.4, and 60 for the dithio, thio, sulfoxo, and sulfone polymers, respectively, when Charlesby's equation (13) is used along with GPC molecular weight results. Whereas these values might seem quite high, polybutylene sulfone (PBS) has been reported to have G_s values of 12.2 and 23.7 *in vacuo* and in air, respectively (14). However, since the mass absorption coefficient for the more massive cobalt unit is 3.6 times that of PBS, the value we have obtained is reasonable. The electron spin resonance spectra of the irradiated polymers suggest radicals centered primarily on the sulfur atoms, with about 5% delocalization to the cobalt centers based on the hyperfine structure of the dithio and thio polymers. No hyperfine splitting is observed for the sulfone polymer, and the monomer shows no ESR signal at all. This varifies the observation that no spectral change is observed for extensive cobalt-60 irradiation of the monomer in methanol solutions. Evidence for SH peaks about 2500 cm^{-1} has been obtained by Fourier transform infrared spectroscopy after irradiation. Also, a loss in the intensity of the symmetrical SO_2 stretch near 1160 cm^{-1} after irradiation has been observed for the sulfone polymer. These results coupled with our ability to make films of the dithio polymer on silicon wavers which have oxidized surfaces looks encouraging. Unfortunately, the films peel from the surface when treated with the solvent combinations we have used in an attempt to determine the sensitivity to electron beams.

We have also expanded our studies to include chromium(III) systems. However, for the chromium centers we have chosen the more volatile trifluoro (tfa^-) and hexafluoro (hfa^-) derivatives of 2,4-pentatedione. Since the fluorinated derivatives are deactivated relative to the electrophilic attack used in these polymerizations, the $Cr(acac)_2(tfa)$ mixed ligand complex has been used initially to obtain polymeric products with sulfur halides.

We have also nitrated the Cr(acac)$_2$-(tfa) complex and reduced the nitro groups to amines to provide links with organic oligomers. Unfortunately, the first nitro together with the trifluoro group deactivates the system such that no dinitro product can be obtained.

- SUMMARY

Four cobalt polymers have been synthesized, three of which are very sensitive to gamma irradiation with resulting G_S values which exceed any known organic polymers. Furthermore, the cobalt is not released during the scission reactions. Films which adhere well enough for commercial use have not yet been obtained for the cobalt systems.

Acknowledgement.--The authors acknowledge the support of the Office of Naval Research for this reseach.

REFERENCES

1. Bowden, M. J. and Turner, S. R. "Electronic and Photonic Applications of Polymers," Amer. Chem. Soc., Washington, D.C., 1988, Chapter 1, 55 references.

2. Choppin, G. R. and Rydberg, J. "Nuclear Chemistry: Theory and Practice," Pergamon Press, Oxford, 1980.

3. Archer, R. D., Hardiman, C. J., Grybos, R., Chien, J. C. W., U. S. Patent No. 4,693,957 (Sept. 1987).

4. Archer, R. D., Hardiman, C. J., and Lee, A. Y. in "Photochemistry and Photophysics of Coordination Compounds," H. Yersin and A. Vogler, eds., Springer Verlag, Berlin, 1987, pp 285-90.

5. Archer, R. D., Tramontano, V. J., Wang, B., and West, P. V., Proc. 11th Conf. Coord. Chem., Smolenice, CSSR, 1987, pp. 1 - 6.

6. Archer, R. D., Wang, B., Tramontano, V. J., Lee, A. Y., and Ochaya, V. O. in "Inorganic and Organometallic Polymers," Zeldin, M., Wynne, K. J. and Allcock, H. R., eds., Amer. Chem. Soc., Washington, DC, 1987, pp 463-68.

7. Lintvedt, R. L. in "Concepts of Inorganic Photochemistry," A. W. Adamson and P.D. Fleischauer, eds., Wiley, NY, 1975, p. 299.

8. Rosser, R. J. and Whitt, F. R. J. Appl. Chem., 1960, 10, 229.

9. Perrin, D. D., Armarego, W. L. and Perrin, D. R., "Purification of Laboratory Chemicals," Pergamon Press, Oxford, 1980.

10. Laurie, S. H. Austr. J. Chem., 1968, 21, 679.

11. Palmer, R. A., Fay, R. C.., and Piper, T. S., Inorg. Chem., 1964, 3, 875.

12. Wang, B. and Archer, R. D. Polym. Matl. Sci. Engr. 59, 120 (1988).

13. Dole, M. "The Radiation Chemistry of Macromolecules," Vol. II, Academic Press, NY, 1973, p. 101.

14. Brown, J. R. and O'Donnell, J. H., Macromolecules, 1970, 3, 265; Ibid., 1972, 5, 109.

TECHNICAL REPORT DISTRIBUTION LIST, GENERAL

	No. Copies
Office of Naval Research Chemistry Division, Code 1113 800 North Quincy Street Arlington, VA 22217-5000	3
Commanding Officer Naval Weapons Support Center Attn: Dr. Bernard E. Douda Crane, IN 47522-5050	1
Dr. Richard W. Drisko Naval Civil Engineering Laboratory Code L52 Port Hueneme, California 93043	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	2 high quality
David Taylor Research Center Dr. Eugene C. Fischer Annapolis, MD 21402-5067	1
Dr. James S. Murday Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375-5000	1
Dr. Ronald L. Atkins Chemistry Division (Code 385) Naval Weapons Center China Lake, CA 93555-6001	1
Chief of Naval Research Special Assistant for Marine Corps Matters Code 00MC 800 North Quincy Street Arlington, VA 22217-5000	1
Dr. Bernadette Eichinger Naval Ship Systems Engineering Station Code 053 Philadelphia Naval Base Philadelphia, PA 19112	1
Dr. Sachio Yamamoto Naval Ocean Systems Center Code 52 San Diego, CA 92152-5000	1
David Taylor Research Center Dr. Harold H. Singerman Annapolis, MD 21402-5067 ATTN: Code 283	1

[illegible]

[illegible]

Dr. [illegible]
School of Chemical Engineering
Georgia Institute of Technology
Atlanta, GA 30332

4132033

Dr. Harry R. Allcock
Department of Chemistry
Pennsylvania State University
University Park, PA 16802

4132007

Dr. Ronald D. Archer
Department of Chemistry
University of Massachusetts
Amherst, MA 01003

413c028

Dr. William J. Bailey
Department of Chemistry
University of Maryland
College Park, MD 20742

413a006

Dr. Frank D. Blum
Department of Chemistry
University of Missouri - Rolla
Rolla, MO 65401

413m005

Dr. F. James Boerio
Materials Science & Engineering Dept.
University of Cincinnati
Cincinnati, Ohio 45221

413m012

Dr. Chris W. Allen
Department of Chemistry
University of Vermont
Burlington, VT 05405

413c012

Dr. Ali S. Argon
Mechanical Engineering Department
Massachusetts Institute of Technology
Cambridge, MA 02139

a400005df

Dr. Kurt Baum
Fluorochem, Inc.
680 S. Ayon Avenue
Azusa, CA 91702

4000021sbi

Dr. Len J. Buckley
Naval Air Development Center
Code 6063
Warminster, PA 18974

Dr. Ivan Caplan
DTNSRDC Annapolis
Code 0125
Annapolis, MD 21401

Dr. Robert E. Cohen
Department of Chemical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

4132001

Dr. E. Fischer
DTNSRDC Code 2853
Annapolis, MD 21402

Dr. Curtis W. Frank
Department of Chemical Engineering
Stanford University
Stanford, CA 94305

413h005

Dr. Gregory S. Girolami
School of Chemical Sciences
University of Illinois
Urbana-Champagne, IL 61801

4132014

Dr. Robert H. Grubbs
Department of Chemistry
California Institute of Technology
Pasadena, CA 91124

4132019

Dr. James F. Haw
Department of Chemistry
Texas A&M University
College Station, TX 77843

413c039

Dr. Stuart L. Cooper
Department of Chemical Engineering
University of Wisconsin
Madison, WI 53706

4132006

Dr. Warren T. Ford
Department of Chemistry
Oklahoma State University
Stillwater, OK 74078

413h006

Dr. John K. Gillham
Department of Chemical Engineering
Princeton University
Princeton, New Jersey 08544

413c005

Dr. Bernard Gordon
Department of Polymer Science
Pennsylvania State University
University Park, PA 16802

413c025

Dr. Henry K. Hall
Department of Chemistry
University of Arizona
Tucson, AZ 85721

413j009

Dr. Alan J. Heeger
Department of Physics
University of California, Santa Barbara
Santa Barbara, CA 93106

4132012

Dr. Pat J. Hendra
Department of Chemistry
University of Southampton
Highfield Southampton 509 5NH
United Kingdom
4134001

Dr. Bruce S. Hudson
Department of Chemistry
University of Oregon
Eugene, Oregon 97403

413c018

Dr. Hatsuo Ishida
Department of Macromolecular Science
Case Western Reserve University
Cleveland, OH 44106

413m008

Dr. Paul M. Lahti
Department of Chemistry
University of Massachusetts
Amherst, MA 01003

413c037

Dr. Robert W. Lenz
Polymer Science and Engineering Dept.
University of Massachusetts
Amherst, MA 01002

441c013

Dr. Alan D. MacDiarmid
Department of Chemistry
University of Pennsylvania
Philadelphia, PA 19104

a400004df

Dr. Charles E. Hoyle
Department of Polymer Science
University of Southern Mississippi
Hattiesburg, MS 39406-0076

413c026

Dr. Leonard V. Interrante
Department of Chemistry
Rensselaer Polytechnic Institute
Troy, NY 12181

413c014

Dr. Jeffrey T. Koberstein
Institute of Materials Science
University of Connecticut
Storrs, CT 06268

4132013

Dr. Richard M. Laine
Washington Technology Center
University of Washington
Seattle, WA 98195

s400033srh

Dr. Geoffrey Lindsay
Chemistry Division - Code 087
Naval Weapons Center
China Lake, CA 93555

4132036

Dr. Chris W. Macosko
Materials Science & Engineering Dept.
University of Minnesota
Minneapolis, MN 55455

4132029

Dr. Joseph H. Magill
Materials Science & Engineering Dept.
University of Pittsburgh
Pittsburgh, PA 15161

413c013

Dr. Tobin J. Marks
Department of Chemistry
Northwestern University
Evanston, IL 60201

413c030

Dr. Krzysztof Matyjaszewski
Department of Chemistry
Carnegie Mellon University
Pittsburgh, PA 15213

413j002

Dr. William B. Moniz
Code 6120
Naval Research Laboratory
Washington, DC 20375-5000

4132012

Dr. Virgil Percec
Department of Macromolecular Science
Case Western Reserve University
Cleveland, OH 44106-2699

413c024

Dr. Roger S. Porter
Dept. of Polymer Science & Engineering
University of Massachusetts
Amherst, MA 01002

413m006

Dr. Leo Mandelkern
Department of Chemistry
Florida State University
Tallahasee, FL 32306-3015

4132018

Dr. Lon J. Mathias
Department of Polymer Science
University of Southern Mississippi
Hattiesburg, MS 30406-0076

413m003

Dr. James E. McGrath
Department of Chemistry
Virginia Polytechnic Institute
Blacksburg, VA 24061

4132007

Dr. Kay L. Paciorek
Ultrasystems Defense and Space, Inc.
16775 Von Karman Avenue
Irvine, CA 92714

s400029srh

Dr. Martin Pomerantz
Department of Chemistry
University of Texas at Arlington
Box 19065
Arlington, TX 76019-0065
a400008df

Dr. T. J. Reinhart, Jr.
Nonmetallic Materials Division
Air Force Materials Laboratory (AFSC)
Wright-Patterson AFB, OH 45433

Dr. Arnost Reiser
Insitute of Imaging Sciences
Polytechnic University
333 Jay Street
Brooklyn, NY 11201

4132022

Dr. Charles M. Roland
Code 6120
Naval Research Laboratory
Washington, DC 20375-5000

413m009

Dr. Ronald Salovey
Department of Chemical Engineering
University of Southern California
Los Angeles, CA 90089

413m010

Dr. Jerry I. Scheinbeim
Dept. of Mechanics & Materials Science
Rutgers University
Piscataway, NJ 08854

4132009

Dr. L. E. Sloter
Code Air 931-A
Naval Air Systems Command
Washington, D. C. 20361-9310

Dr. Dietmar Seyferth
Department of Chemistry
Massachusetts Institute of Technology
Cambridge, MA 02139

413c004

Dr. [illegible]
Department of Chemical Engineering
[illegible]
Ithaca, NY [illegible]

413c011

Dr. Michael F. Rubner
Materials Science & Engineering Dept.
Massachusetts Institute of Technology
Cambridge MA 02139

413m007

Dr. Jacob Schaefer
Department of Chemistry
Washington University
St. Louis MO 63130

413m001

Dr. Lawrence R. Sita
Department of Chemistry
Carnegie Mellon University
Pittsburgh, PA 15213

4132030

Dr. Richard R. Schrock
Department of Chemistry
Massachusetts Institute of Technology
Cambridge, MA 02139

4132038

Dr. David S. Soane
Department of Chemical Engineering
University of California, Berkeley
Berkeley, CA 94720-9989

413h004

Dr. Les H. Sperling
Materials Research Center #32
Lehigh University
Bethlehem, PA 18015

413c002

Dr. C. S. Sung
Institute of Materials Science
University of Connecticut
Storrs, CT 06268

413m011

Dr. C. H. Wang
Department of Chemistry
University of Utah
Salt Lake City, Utah 84112

413c020

Dr. Robert A. Weiss
Department of Chemical Engineering
University of Connecticut
Storrs, CT 06268

a400006df

Dr. Garth L. Wilkes
Department of Chemical Engineering
Virginia Polytechnic Institute
Blacksburg, VA 24061

4132020

Dr. Richard S. Stein
Polymer Research Institute
University of Massachusetts
Amherst, MA 01002

4132008

Dr. Sukant K. Tripathy
Department of Chemistry
University of Lowell
Lowell, MA 01854

4132016

Dr. Kenneth B. Wagener
Department of Chemistry
University of Florida
Gainesville, FL 32611

a400007df

Dr. George M. Whitesides
Department of Chemistry
Harvard University
Cambridge, MA 02138

4132010